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Working Paper 2007-20
August 2007

WORKING PAPER SERIES

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Abstract: During the past thirty-five years, energy use as a fraction of output has dropped significantly at both the household and the firm levels. Therefore, we investigate a dynamic stochastic generalized equilibrium model economy's response to an energy price hike for different firm and household energy shares. Simulation results indicate that the economy's output response is mainly determined by the firm energy share. Increasing the household energy share while keeping firm energy share constant actually decreases the output response.

JEL classification: E32, Q43

Key words: energy prices, business cycles, durable goods

The authors thank seminar participants at the Federal Reserve Bank of Atlanta for helpful comments. The views expressed here are the authors' and not necessarily those of the Federal Reserve Bank of Atlanta or the Federal Reserve System. Any remaining errors are the authors' responsibility.

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1 Introduction

Our research is motivated by the fact that during the past 35 years, energy use as a fraction of output has dropped significantly both for households and firms. For example, energy use by households dropped from an average 5.29 percent of output during the 1970 to 1985 time-period to 3.97 percent during 1986-2005 – a drop by about 25 percent.[1] On the firm side the reduction in energy use is even more pronounced at 36 percent.

We set up a dynamic stochastic general equilibrium (DSGE) model with stochastic energy prices and energy use both on the firm and household side. The model is identical to that used in Dhawan and Jeske (2006). We then study the size of the output drop in response to energy price increases. Specifically, we study how sensitive is the output drop to targeting alternative steady state firm and household energy use.

Simulation results indicate that the economy's output response is mainly determined by the firm energy share. In fact, keeping firm energy share constant, increasing the household energy share actually decreases the output response. Thus, a normative implication is that if policy makers are concerned about output and employment fluctuations from energy price shocks, encouraging a reduction in the energy share on the production rather than the household side ought to be their primary concern. Additionally, we find that a model with higher energy use calibrated to the 1970-1985 period generates slightly higher output responses to an energy price hike, but still not large enough to account for a sizeable share of output fluctuations confirming the results of Kim and Loungani (1992).

2 Model

The model is identical to the one in Dhawan and Jeske (2006). Households consume non-durables and services outside of energy N, a service flow of durables D and household energy use E_h. They supply labor H and capital K to firms who combines them together with firm energy consumption E_f into output Y. Both household and firm energy consumption have to be purchased from abroad at relative price P.

[1]We compute energy shares as nominal spending on energy divided by nominal GDP at annual frequency.

Then the social planner's problem is:

$$\max E \sum_{t=0}^{\infty} \beta^t \left[\varphi \log N_t^{\gamma} \left(\theta D_{t-1}^{\rho} + (1-\theta) E_{h,t}^{\rho} \right)^{\frac{1-\gamma}{\rho}} + (1-\varphi) \log (1 - H_t) \right]$$

subject to:

$$\begin{aligned}
N_t + I_{d,t} + I_{k,t} + P_t (E_{h,t} + E_{f,t}) &= Y_t - AC_t^d - AC_t^k & (1) \\
Y_t &= Z_{y,t} \left(\eta K_{t-1}^{\psi} + (1-\eta) E_{f,t}^{\psi} \right)^{\frac{\alpha}{\psi}} H_t^{1-\alpha} & (2) \\
I_{d,t} &= D_t - (1-\delta_d) D_{t-1} & (3) \\
I_{k,t} &= K_t - (1-\delta_k) K_{t-1} & (4) \\
AC_t^d &= \frac{\omega_d}{2} \left(\frac{D_t - D_{t-1}}{D_{t-1}} \right)^2 & (5) \\
AC_t^k &= \frac{\omega_k}{2} \left(\frac{K_t - K_{t-1}}{K_{t-1}} \right)^2 & (6)
\end{aligned}$$

where I_d and I_k are investment in durables and fixed capital, respectively. AC_t^d and AC_t^k are quadratic adjustment costs to changing the stock of durable and fixed capital, respectively. Z_y is total factor productivity (TFP).

3 Calibration

3.1 Preference and technology parameters

One model period corresponds to one quarter in the data. Throughout this paper we assume that $\alpha = 0.36$ and the time preference factor is $\beta = 0.99$. As in Kim and Loungani we use $\psi = -0.7$ and set $\rho = -3.0$.[2] We keep the two calibration targets $K/Y = 12$ and $H = 0.3$ fixed. These two targets together with the remaining four targets D/Y, I_D/Y, E_h/Y, and E_f/Y pin down six remaining parameters $\gamma, \theta, \eta, \varphi, \delta_d, \delta_k$.[3] In Table 1 we detail the average value of the four ratios during the entire period 1970-2005 as well as the two subperiods 1970-1985 and 1986-2005. The durables to output ratio (D/Y) and the investment in durables to output ratio (I_D/Y) were

[2]Our results are robust for a variety of different values of ρ. We pick this particular value as it generates the volatility of household energy use close to that found in the data as shown in Dhawan and Jeske (2006).

[3]See the appendix in Dhawan and Jeske (2006) for the details of the calibration exercise.

essentially unchanged between the two subperiods. Thus, we fix the targets for D/Y and I_D/Y at their average over the 1970-2005 period. However, the energy ratios E_h/Y and E_f/Y changed dramatically between the two subperiods. Hence, we create a grid over the E_h/Y and the E_f/Y targets (equal step size of 10 points) and simulate the economy for all possible combinations.

Table 1: Calibration Targets

	Entire period 1970-2005	Subperiod 1 1970-1985	Subperiod 2 1986-2005	Change: Subperiod 1 vs. 2
D/Y	1.3668	1.3582	1.3737	+1.14%
I_D/Y	0.0932	0.0927	0.0935	+0.82%
E_h/Y	0.0456	0.0529	0.0397	−24.87%
E_f/Y	0.0517	0.0646	0.0414	−35.84%
$E_h/Y + E_f/Y$	0.0973	0.1175	0.0812	−30.90%

Source: Dhawan and Jeske (2006), Bureau of Economic Analysis, Energy Information Administration.

3.2 Stochastic process for energy prices

We assume that the energy price follows an ARMA(1,1) process.

$$p_t = \rho_p p_{t-1} + \varepsilon_{p,t} + \rho_\varepsilon \varepsilon_{p,t-1} \text{ with } \varepsilon_{p,t} \overset{iid}{\sim} N\left(0, \sigma_p^2\right), \tag{7}$$

with $\rho_p = 0.9753$, $\rho_\varepsilon = 0.4217$ and $\sigma_p = 0.0308$ as in Dhawan and Jeske (2006).[4]

4 Numerical Results

We use the stochastic perturbation method, i.e., log-linearization around the steady state, to approximate the dynamics of our economy. From the first order conditions (see Dhawan and Jeske (2006)), we derive eleven conditions guiding the dynamic behavior of eleven variables N, D, E_h, H, W, E_f, K, R, Y, I_D, I_K plus two equations for the shocks. We then run the program

[4]Our focus in this paper is on the response of output to an energy price shock only. As Dhawan and Jeske (2006) pointed out, a model without adjustment costs generates excess volatility of investment in durables and fixed capital. Thus, we simulated the model with productivity shocks as in Cooley and Prescott (1995) in addition to energy price shocks to pin down the exact adjustment cost parameters of equations (5) and (6) so as to match the observed investment volatilities in the data. We do so in each of the 100 economies, because investment volatilities depend on the energy shares. We also simulated the economy in the absence of adjustment costs and the results were qualitatively similar to the ones we report in the next section.

Dynare Version 3.0 to generate a first order approximation for the policy function (see Collard and Juillard (2001) for the methodological details).

We study how an energy price shock affects output under the alternative targets for the energy shares on the household and the firm side. We use three different measures to study the output effect:

1. *The maximum drop in output.* Compute the impulse response of output to a one standard deviation shock in the energy price and measure the maximum drop in output.

2. *The average drop in output.* As a measure of the average output loss we use:

$$L^y = \frac{\sum_{t=1}^{\infty} \beta^{t-1} \left(\exp\left(\tilde{y}_t\right) - 1\right)}{\sum_{t=1}^{\infty} \beta^{t-1}} = (1-\beta) \sum_{t=1}^{\infty} \beta^{t-1} \left(\exp\left(\tilde{y}_t\right) - 1\right) \tag{8}$$

   where $\tilde{y}_t$ is the impulse response function, i.e., the log deviation from the steady state. One can think of L^y as translating the time-varying output loss in the impulse response function into one constant permanent loss in every period.

3. *The output volatility due to energy price shocks.* We simulate 1000 economies of length 144 quarters each (same length as the interval 1970Q1-2005Q4) and compute the average output volatility over the 1000 simulations due to the energy price shocks.

We plot our results in Figure 1 where the three panels are contour plots of the alternative measures. The energy shares E_h/Y and E_f/Y in the upper right corner represent the 1970-1985 subperiod and the lower left corner represents the 1986-2005 subperiod.

First, notice that the impact on output is small across all calibrations and the three alternative measures. The maximum output drop after a one standard deviation shock to the energy price is below 0.3 percent. Thus, a two-standard deviation shock to the energy price brings about an output drop of no more than 0.6 percentage points below steady state, hardly enough to cause a recession. Our results are, therefore, in the spirit of Kim and Loungani (1992) who also found that energy shocks are not the prime cause for business cycle fluctuations.

We also find that for all three alternative measures it is solely the firm energy share that determines the energy shock impact. In fact, if we increase the household energy share we even slightly *decrease* the energy effect on output when we examine the slope of the contours.

To help understand this result, we pick three specific calibrations with different energy shares as listed in Table 2. Our benchmark calibration is for the economy with firm and household energy shares in the 1970 to 1985 time-period. Next, for calibration LF, we lower the firm energy share to match the average for the 1986-2005 subperiod, while keeping the household energy share as in the benchmark case. The third calibration, called LH, is the one with lower household energy use calibrated to the average in the 1986 to 2005 time-period, while keeping the firm energy ratio as in the benchmark case.

Table 2: Energy Shares

	Energy share	
Calibration	Household	Firm
Benchmark: (energy shares as in 1970-1985)	5.29%	6.46%
LF: Lower E_f/Y (firm share as in 1986-2005)	5.29%	4.14%
LH: Lower E_h/Y (household share as in 1986-2005)	3.97%	6.46%

In Figure 2, we plot the impulse response functions (IRFs) to a one standard deviation shock to the energy price in the three alternative calibrations. Consistent with the observations from Figure 1, the benchmark and the LH calibration have very similar output impulse response functions, while the LF calibration displays a much smaller impact on output.

Notice that the IRFs for I_d and I_k display a rebalancing effect: investment in durables drops substantially as a response to an energy price hike to allow for a smaller drop (or even a rise in the LF calibration) in fixed investment in the initial period of the shock. As pointed out by Dhawan and Jeske (2006), the source of the rebalancing effect is the difference in the energy to capital ratio between the firm and the household. That differential is most pronounced in the case of our second calibration LF when we lowered firm energy use.

Comparing the IRFs for firm energy use in the three alternative calibrations, we notice that the LF calibration displays the lowest percentage drop. In contrast, in the IRFs for household energy use, the percentage drop is the lowest in the LH calibration. One can call this a rebalancing effect of energy use: if the household energy share is high relative to the firm energy share, the representative household can more easily reduce the use of the more abundant energy component E_h.

To further analyze the source of the differences between the output IRFs, we decompose the output response into input components: hours worked, the capital stock and firm energy use. Assuming constant productivity we can log-linearize the output equation (2):

$$y_t = \zeta_h h_t + \zeta_k k_{t-1} + \zeta_e e_{f,t} \tag{9}$$

where the small letters stand for the log-deviation from the steady state and the weights ζ are:

$$\zeta_h = (1-\alpha)\,,\ \zeta_k = \alpha \frac{\eta K^{\psi}}{\eta K^{\psi} + (1-\eta)\,E_f^{\psi}},\ \zeta_e = \alpha \frac{(1-\eta)\,E_f^{\psi}}{\eta K^{\psi} + (1-\eta)\,E_f^{\psi}} \tag{10}$$

We plot the three components of equation (9) in Figure 3. Initially it is the energy component $\zeta_e e_{f,t}$ that is contributing the most to the output drop in the three calibrations, with calibration LF having the smallest impact. This happens because the drop in firm energy use (E_f) is lowest in the calibration LF (see Figure 2), coupled with the fact that the parameter ζ_e is also smaller because of the lower energy to capital ratio.

In all three calibrations, the initial contribution from capital ($\zeta_k k_{t-1}$) is negligible, but over time the cumulative effect of the capital adjustment is substantial. After 40 quarters, capital's contribution is larger than those of hours worked and energy. The capital adjustment in the LF calibration is also much smaller than the benchmark calibration. This is despite the fact that the LF calibration, with a lower firm energy share compared to the benchmark, has a higher ζ_k. However, the LF calibration has a very strong rebalancing effect, which results in a lower drop in the capital stock than the benchmark and more than makes up for the higher ζ_k. Finally, hours worked contribute about 0.1 percentage points to the output drop in $t = 2$ (roughly a third of the total) in both the benchmark case and the LH calibration and about 0.07 percentage points in the LF calibration.

Figure 3 also sheds light on why the output drop is more in the LH calibration than in the benchmark calibration. The difference is almost entirely due to hours worked dropping slightly more than in the benchmark. In the LH calibration, firm energy use drops slightly more than in the benchmark, but its direct effect on output is very small – the lines for the LH economy and the benchmark in the lower panel of Figure 3 are almost indistinguishable. However, the slightly larger drop in E_f in the LH calibration is enough to lower the marginal product of labor and cause the fall in hours. This indirect effect causes the larger output drop in the LH calibration.

5 Conclusion

Our simulations show that the impact of an energy price hike on output is mainly due to the firm energy share. Our output decomposition analysis indicated that this is the result of two forces. First, the direct effect by construction, is the share of energy in the production function. Second, is the rebalancing of energy use by the representative household, whereby the percentage drop in firm energy use is smaller when energy share in the production function is lower. We also find that decreasing the household energy share slightly increases the impact of an energy price increase on output. This effect is due to a larger drop in hours in the economy with less household energy use. Our work has a policy implication, too. If policy makers are concerned about output and employment disruptions from energy price shocks, finding ways to reduce the energy share on the production side ought to be their primary concern.

References

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[4] Dynare, Version 3.0

[5] Kim, In-Moo and Prakash Loungani. 1992. "The role of energy in real business cycle models" *Journal of Monetary Economics* 29: 173-89.

Figure 1: Effect of energy price shocks on output (contour plots)

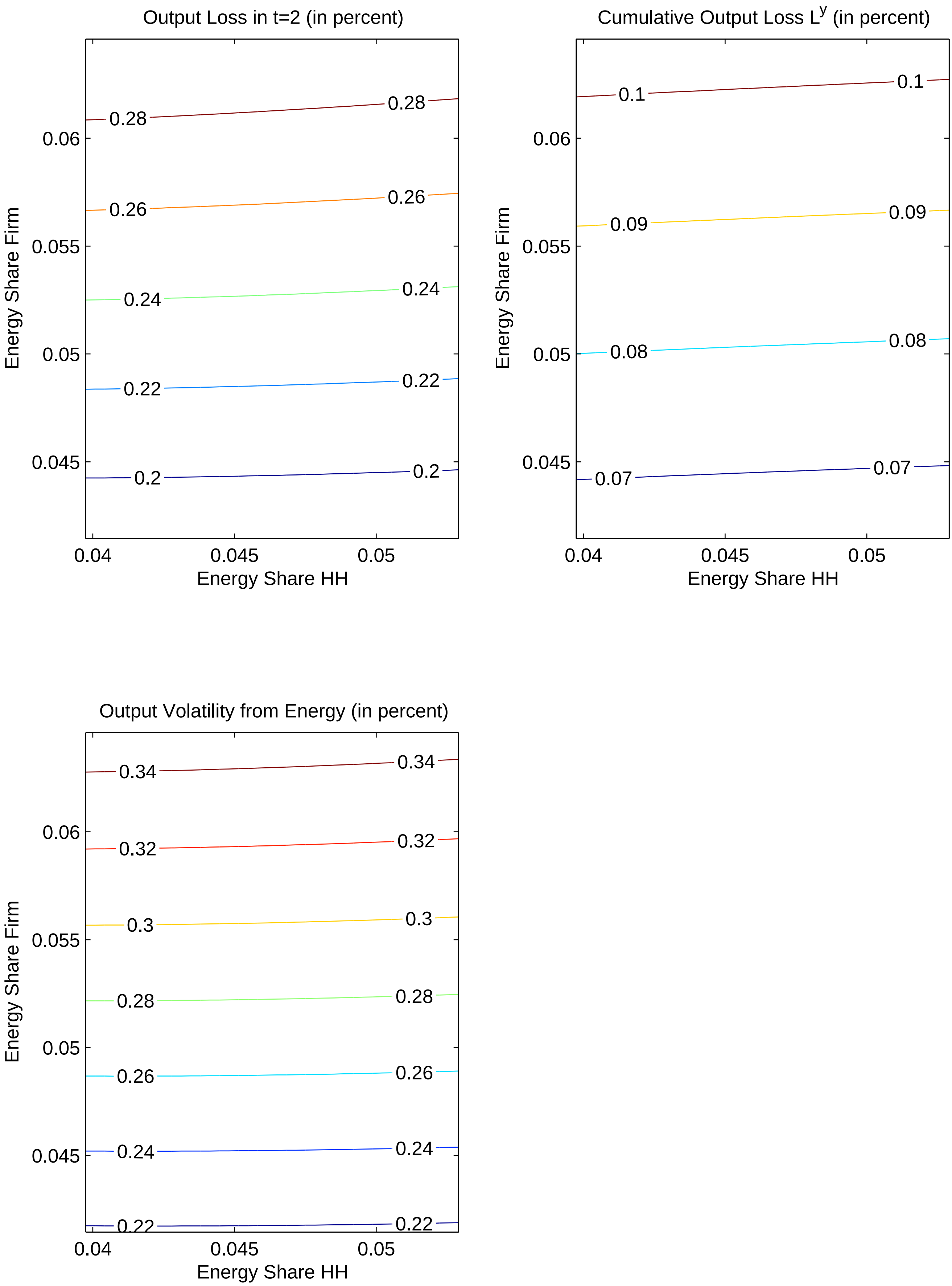

Figure 2: Impulse Responses to a one standard deviation shock to P. In percent.

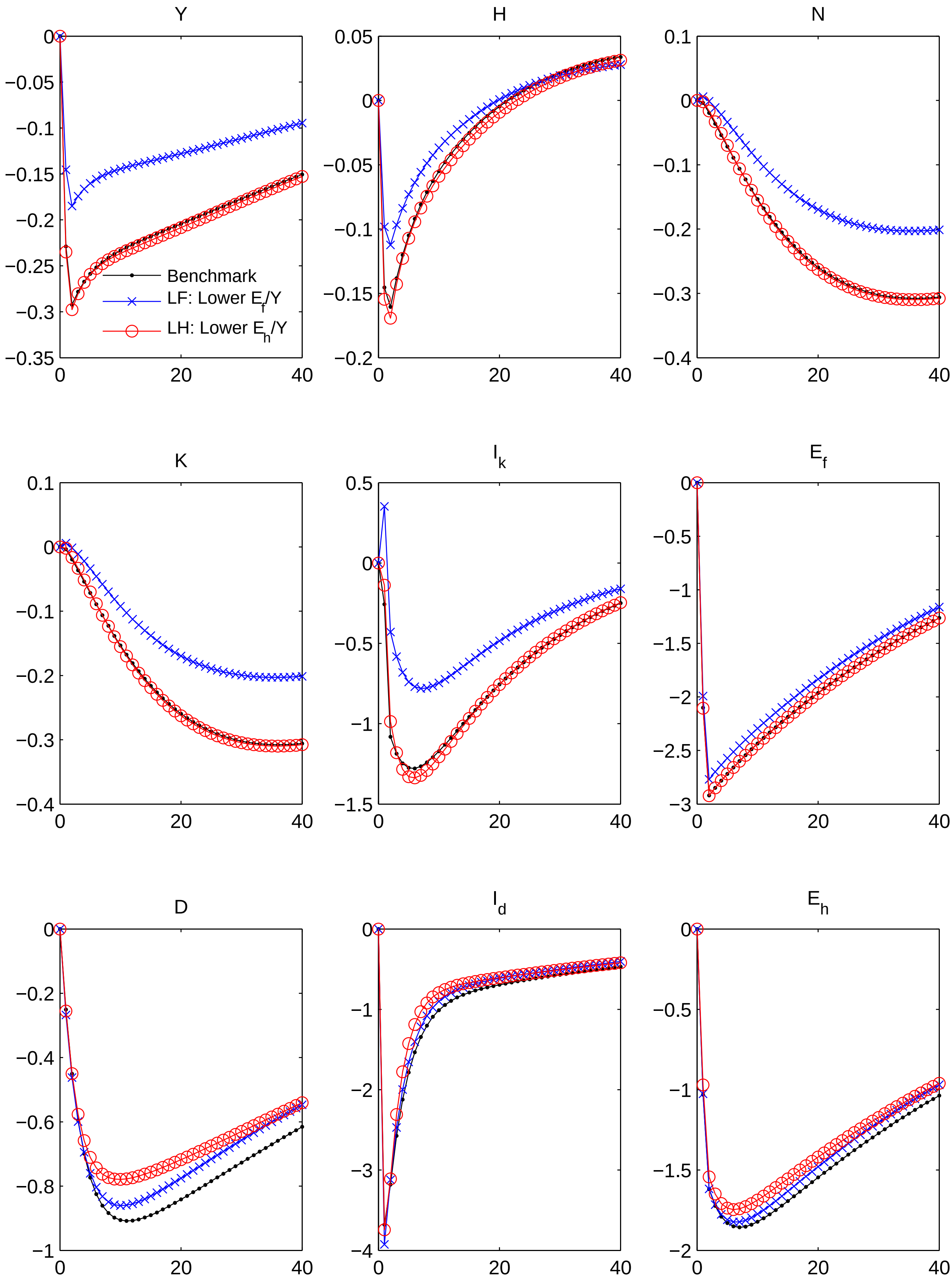

Figure 3: Decomposing the output impulse response into its components: hours worked, capital stock and energy use. For easier comparison we used the same scale in the three charts. In percent.